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Larsen, Torben

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TORBEN LARSEN

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AALBORG UNIVERSITETSCENTER
LABORATORIET FOR HYDRAULIK OG HAVNEBYGNING
SOHNGARDSHOLMSVEJ 57 DK-9000 AALBORG DANMARK

INSTITUTE OF CIVIL ENGINEERING HYDRAULICS LABORATORY

AALBORG UNIVERSITY

Sohngårdsholmsvej 57 DK-9000 Aalborg Denmark Tel (08) 142333

Torben Larsen

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# REAL RAINFALL TIME SERIES FOR STORM SEWER DESIGN

by

Torben Larsen
Department of Civil Engineering
University of Aalborg
Postbox 159, DK-9100 Aalborg, Denmark

## ABSTRACT

The paper describes a simulation method for the design of retention storages, overflows etc. in storm sewer systems. The method is based on computer simulation with real rainfall time series as input and with the aply of a simple transfer model of the ARMA-type (autoregressiv moving average model) as the model of the storm sewer system. The output of the simulation is the frequency distribution of the peak flow, overflow volume etc. from the overflow or the retention storage. The parameters in the transfer model is found either from rainfall/runoff measurements in the catchment or from one or a few simulations with an advanced hydraulic computer model.

## INTRODUCTION

Since the first computer models for storm sewer simulation was introduced nearly twenty years ago an intensive development to improve the models has taken place. As a result of this impressive work carried out by some of the best researches in the world in the field of computational hydraulics it is now possible to simulate the flow in complex systems of pipes, manholes etc. by numerical models, which include all the elements of the basic hydrodynamical equations for one-dimensional, unsteady flow. When the computer capacity is increasing significant in the next decade, it should be expected that those models will be used very commonly in the future design of storm sewer system.

For several years it has been a general practic to use the peak flow for a given return period as the design criteria for the different structural elements in the storm sewer system. However several examples can be given where the peak flow is not the most suitable design parameter. Take the discharge from an overflow to smaller lake. From the lake's point of view the peak flow is not very interesting, but the total overflow volume could be a more relevant parameter to use in the design procedure. Due to the complex relation between rainfall intensity and the overflow discharge, it is not possible to establish a connexion between peak flow and overflow volume. Therefore real rainfall time series has to be used as input for simulation if a unique statistical output is wanted.

Combining advanced hydraulic computer models and long time series of real rainfall will not for the moment be a practical and economical tool in storm sewer design, so the aim of this project is to present a simplified method, which approximate the behaviour of the sewer system reasonably accurate and which moreover is so simple that real time series can be used as input. It is important to emphazise that the method here suggested does not have the intension of presenting any definite and sophisticated solution. The main stress has been laid on simplicity and statistical consistency.

## THE RAINFALL TIME SERIE

The rainfall time serie used in this project was recorded in Gentofte, a suburb north of Copenhagen, in the period from 1933 to 1962. Only rainfalls in the summer, May to October, is included and only rainfalls greater than 3 mm has been used. Totally the time series consist of approximately 1100 rain events. The data is part of a greater data base of danish rainfall data, which now is building up by SPILDEVANDSKOMITEEN (Danish Committee of Sewer Systems). Further details about the data is reported by Johansen (1978).

A graphical plot of a part of the rainfall time serie is seen on Fig. 1a. The rainfalls are arranged as one-dimensional time serie where the rainfalls is separated by a fixed dry weather period of the shortest possible duration in relation to the time scale (delay) of the sewer system including the retention storage. In the example shown in this paper a dry weather period of 3 hours has been used.

## SURFACE LOSSES

Only a simple surface model has been applied to the project. The model removes the first part of the rainfall as a depression storage. Furthermore the model is based on the assumption of a fixed relation between rainfall intensity and surface runoff. The depression storage has only been taken into account if the time between two succeeding rainfalls was less than 2 hours. As the data file also include some information about sporadic rain less than 3 mm it has been possible to reduce the depression loss with the volume of sporadic rain, if this has occured less than one hour before the real rainfall started.

On grounds of principle the dynamic behaviour of the surface processes has not been modelled separately, but will be part of the general transfer-model mentioned below.

## THE ARMA-TRANSFORMATION

The main assumption is now that the total runoff process can be described as a linear transformation of net rainfall time serie. As a consequence of the linearity principle the superposition principle is valid and the well known hydrograph analysis can be used.

From the teory of hydrographs it is known that the output from the catchment Q(t) is found from the input, the hyetograph I(t), by the convolution integral

$$Q(t) = \int_{o}^{t} u(t-\tau)I(\tau)d\tau \qquad (1)$$

The function u(t) is the so-called instantanius unit hydrograph. This u(t) can be determined from known series of Q(t) and I(t) applying the Wiener-Hopf expressions (see e.g. Yevjevich (1972)) or by the approach of fourier transform.

The disadvantage of using a numerical instantanius unit hydrograph for hintcasting is that the number of aritmetic calculations in each timestep.is high, so for the purpose of transforming very long series a more simple method would be suitable.

In hydrology different types of filtering techniques as the moving average, linear reservoirs, 1. order autorekursiv filter etc. have been used for many years. But during the last decade the ideas have gathered to a more general theory of the relations between time series, as seen in Box and Jenkins (1976). For the purpose of this project it was decided to describe the retardation and smoothing of the flow in the catchment by a ARMA-type (autoregressiv moving average) model.

The ARMA (p.q.) process is

$$Q_t = a_1 Q_{t-1} + a_2 Q_{t-2} \cdots\cdots + a_p Q_{t-p} + I_t - b_1 I_{t-1} - b_2 I_{t-2} \cdots\cdots - b_q I_{t-q} \qquad (2)$$

| | |
|---|---|
| $Q_t$ , $Q_{t-1}$ .... | are elements in the output time serie |
| $I_t$ , $I_{t-1}$ .... | are elements in the input time serie (transformed to zero mean) |
| $a_1$ , $a_2$ ... $a_p$ | are the autorekursiv parameters |
| $b_1$ , $b_2$ ... $b_q$ | are the moving average parameters |
| t | denotes time |
| p | number of autorekursiv parameters |
| q | number of moving average parameters |

Details in the theory of fitting the parameters can not be shown here, but Box and Jenkins (1976) is recommended. Two problems are in principle involved, the first is the determination of the necessary number of parameters, and the second is the estimation of the parameters themselves.

Identification of the necessary parameters is carried out through the analysis of the autocorrelation and the partial autocorrelation functions of the transformed series. According to "Akaike's Information Criterion" (AIC) it was found, which number of free parameters, which gave minimum estimate of AIC (Hipel et al 1977). This function AIC defines the balance between the number of parameters with the corresponding decrease in the residual variance. AIC is computed from:

$$AIC = -2 \log_{10}(\text{maximum likehood}) \quad +2 \text{ (number of parameters)} \qquad (3)$$

The model parameters is estimated from the maximum likehood method. The maximum likehood function is formulated and its maximum is obtained by minimizing the residuals between the transformed and the measured series by applying so-called Marquardt algorithm. As seen above the identification of the number of parameters and the estimation of parameters can not be separated.

## MODEL OF OVERFLOW AND RETENTION STORAGE

The output from the ARMA-model has now to be transformed through a model of the retention storage including the overflow. This simple model is based on the continuite equation for the reservoir

$$dh/dt\ F(h) = Q_i - Q_b - Q_o \tag{4}$$

h is the water depth in the reservoir

F(h) is the surface area of the reservoir

$Q_i$ is the input from catchment

$Q_b$ is bottomoutflow $Q_b = k_b\ h^{1/2}$

$Q_o$ is overflow $Q_o = 1.89\ k_o\ (h-h_o)^{3/2}$

A Runge-Cutta method is used for the integration of equation (4).

## EXAMPLE

The method has been used on different catchments, but only one example will be shown here. The catchment is situated in a suburb, Birkerød, north of Copenhagen and data of the catchment and the adapted model is listed below.

TABLE 1 Catchment data

| | |
|---|---|
| Total cacthment area | 28.9 ha |
| Average runoffcoefficient | 0.20 |
| Surface loss on reduced area | 0.6 mm |
| Sewerage discharge | 0.005 $m^3/s$ |

TABLE 2 ARMA-model data

| | |
|---|---|
| Time increment in rumerical model | 1 min |
| Number of autorekursiv parameters | p = 1 |
| Number of moving average parameters | q = 4 |
| Autorekursiv parameter | $a_1$ = 0.8864 |
| Moving average parameter | $b_1$ = 0.0130 |
| Moving average parameter | $b_2$ = -0.0426 |
| Moving average parameter | $b_3$ = 0.0020 |
| Moving average parameter | $b_4$ = -0.0120 |

TABLE 3 Retention storage data

| | |
|---|---|
| Bottom surface area | 100 $m^2$ |
| Slope of sides | $45^o$ |
| Height to weir, $h_o$ | 3 m |
| Length of weir, $k_1$ | 2 m |
| Bottom outflow constant, $k_o$ | 0.02 $m^{5/2}/s$ |
| Capacity of sewer after storage | 0.08 $m^3/s$ |

Result from such a computersimulation is shown in Fig. 1 and 2. Fig. 1 shows a short part of the four time series involved in the simulation and gives a direct graphical view of the transformations in the computer. Fig. 2 gives the statistical results of the simulation where the frequency of overflow volume, overflow duration, maximum (peak) flow and height in retention storage is shown in number of events. The period consists of 29 summer half-years and the number of storm events in the serie was 1113.

## DISCUSSION AND CONCLUSION

Several authors (Eagleson, P.S. (1962), Kloet v. der (1977), Chow, V.T. et al (1976)) have discussed the use of a linear transfer model for the urban run-off process. Although the theoretical doubts are numerous, practice shows that such models are reasonably accurate for this purpose. The assumptions are of course that sewer system does not contains any direct unlinearity as overflows, pumbs etc. But probably the most important but indirect assumption is that the system earlier has been designed on the basic of a method of the Lloyd-Davies type, which in general give an oversized system in relation to the design criteria.

The ARMA-filtering here suggested was original initiated as an interpretation of rainfall/runoff measurements and seems from the author's point of view to give a balanced compromise between accuracy and computing speed when it comes to the practical use of real rainfall time series for storm sewer design.

## ACKNOWLEDGEMENTS

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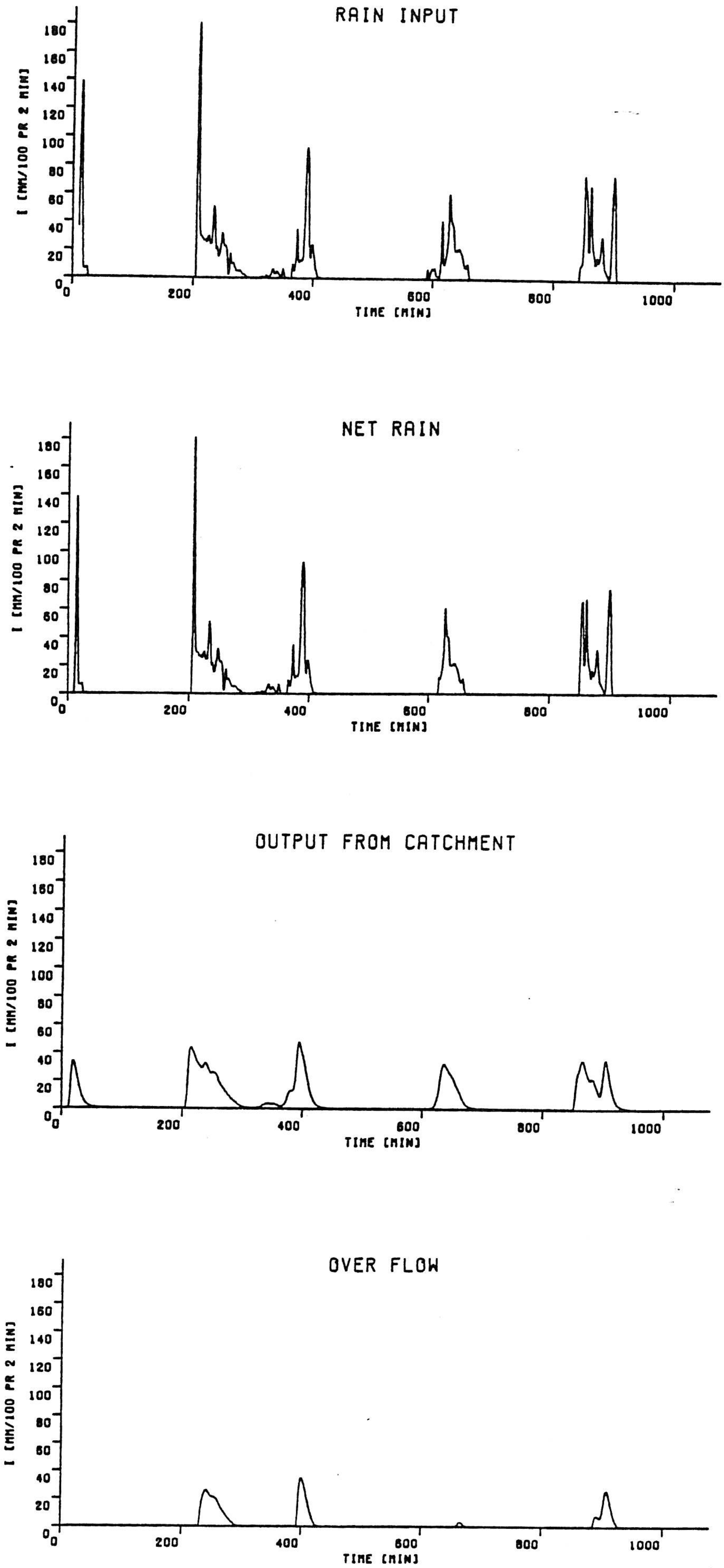
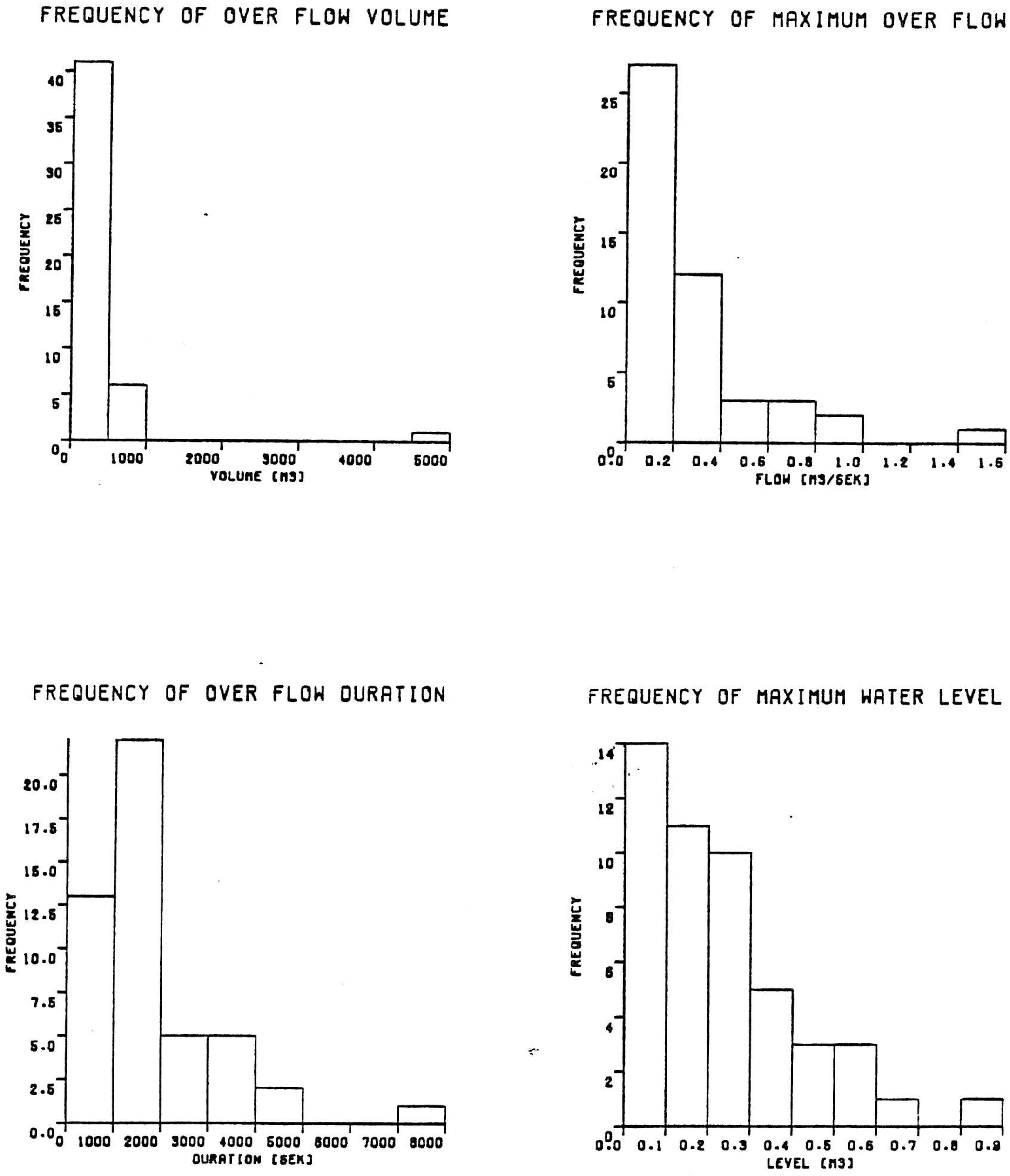

RAIN INPUT
NET RAIN
OUTPUT FROM CATCHMENT
OVER FLOW
I [MM/100 PR 2 MIN]
TIME [MIN]

Figure 1.



FREQUENCY OF OVER FLOW VOLUME
FREQUENCY
0 5 10 15 20 25 30 35 40
0 1000 2000 3000 4000 5000
VOLUME [M3]
FREQUENCY OF MAXIMUM OVER FLOW
FREQUENCY
0 5 10 15 20 25
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
FLOW [M3/SEK]
FREQUENCY OF OVER FLOW DURATION
FREQUENCY
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0
0 1000 2000 3000 4000 5000 6000 7000 8000
DURATION [SEK]
FREQUENCY OF MAXIMUM WATER LEVEL
FREQUENCY
0 2 4 6 8 10 12 14
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
LEVEL [M3]


Figure 2.